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**Description**

This invention relates to the art of interfacing metals having differing thermal expansion characteristics and, more particularly, to the art of compensating for such differences in thermal expansion when such joined metals are used at widely varying temperature conditions.

In modern internal combustion engines, dissimilar metal interfaces have included both rigid and moving interfaces. A rigid interface exists between an aluminum head and an iron-based cylinder block, joined by steel bolts with a gasket interposed therebetween. Similarly, a rigid interface may exist between an aluminum cylinder block and cast-iron main bearing caps attached to the block by steel bolts. The coefficient of thermal expansion of the steel bolts, or of the cast-iron part, relative to the aluminum part, differs considerably and may result in widely differing clamping forces between the parts. The interface can loosen under some temperature conditions that may cause engine performance problems.

Attempts have been made to use gasket materials with excessively low relaxation rates at the rigid head-to-block interface and thereby maintain a more uniform level of bolt forces (see SAE article "Aluminum Engines Require Special Gasketing Techniques", Vol. 91, No. 4, pp. 48-50, 1983). Such techniques are expensive and not totally satisfactory to eliminate all leakage. Other attempts to improve rigid interfaces have included the use of inserts having high resistance to creep which have been cast-in-place in an aluminum head to avoid plastic deformation of the head under the stress of steel bolts (see U.S. patent 4,450,800). The insert in this disclosure is comprised of nickel and iron providing a coefficient of thermal expansion the same as the aluminum head but with greater pressure resistance than aluminum. This, in no way, modifies the thermal expansion characteristic of either interfacing part, thus resulting in the same propensity to looseness.

Moving interfaces exist between rotating members and their bearings or between a reciprocating piston and its bore walls. At the interface between an iron crankshaft and an aluminum bearing support, the prior art has attempted to modify the absorption of impact stress at such interface to eliminate gradual distortion of the support. In U.S. patent 3,089,735, a bearing support insert is used to provide a greater outer surface area than inner surface area. In this disclosure, a cast-in-place insert comprised of aluminum or magnesium is kneaded to have high compression resistance; it is preferably bonded during casting of the block by use of lead, cadmium, tin or zinc. No attempt is made to substantially modify the thermal expansion characteristic of the block at the interface by material substitution.

Although metal matrix composites are known which change the physical characteristics of the metal matrix by introducing a ceramic phase, little application research has been carried out to adapt such technology to dissimilar metal interfaces which may be employed in an internal combustion engine.

According to the present invention there is provided A method of dimensionally stabilizing the interface between metal parts of differing thermal expansion characteristics (TEC), a first part having the higher TEC and a second part having the lower TEC, regardless of temperature variations under normal designed use of such parts, comprising: before bringing together said first part with the second metal part for forming said interface:

- locating an insert in a mould to cast it in place in the first part of the interface,
- introducing molten metal into the mould for such first part,
- characterised in, before locating said insert in the mould

(a) hot extruding a mixture of ceramic fibers having TEC less than either of said parts and rapidly solidified metal powder comprised substantially of the metal having the higher TEC, while aligning the fibers generally along the direction of extrusion, to form a billet;

(b) severing said insert from the billet and shaping it to orient its fibers parallel to at least one direction of anticipated thermal growth of the first part, that would interfere with said interface;

(c) while locating said insert in the mould for positioning it to carry out said orientation of step (b), said insert being preheated to a temperature in the range of 35-45% of the temperature of the molten metal for the first part to be poured into the mould.

Further according to the invention there is provided an assembly of interfacing dissimilar metals in an internal combustion engine, said metals having differing thermal expansion characteristics (TEC), comprising:

(a) a first part comprised of a metal having the higher TEC, said first part presenting a first interface surface;

(b) a second part comprised of a metal having the lower TEC and presenting a second interface surface to mate with said first interface surface, said first part having a cast-in-place metal insert characterised in that the cast-in-place metal insert is a metal matrix composite insert in which the metal of the matrix is substantially the same as the metal of said first part and contains a ceramic phase consisting of ceramic fibers aligned generally in at least one direction of anticipated thermal growth of the second part that may interfere with said interface.

The metal powder may be rapidly solidified and devoid of organic material. Advantageously, the thermal

shock of the molten metal of higher TEC (introduced into the mould) will, upon contact with the insert, break up any oxide coating covering the molten metal to create improved wettability and bonding.

Preferably, the metal of the higher TEC is an aluminum alloy, thus permitting hot extrusion to be carried out using greater than 10:1 reduction, i.e.,  $2.07 \times 10^5$  -  $3.45 \times 10^5$  kPa (30-50 ksi) pressure, and at a temperature greater than 400°C, preferably 500-600°C. The ceramic fibers may preferably be selected from the group consisting of silicon nitride, sialon, silicon carbide, aluminum silicate and alumina. The metal powder may be a metal form or alloy selected from the group consisting of aluminum, titanium, magnesium, copper, and zinc.

Advantageously, an insert for an aluminum metal part is shaped by heating to a temperature of about 300°C for about 20 minutes and bending the insert to conform to the desired configuration. The insert may be arc-shaped and totally immersed as an embedment within a casting used for a rotating bearing support. Alternatively, the insert may be shaped as a cylinder to be deployed as a bushing and exposed at a rigid interfacing surface.

Preferably, the insert is moulded to the cast metal part by die-casting techniques. When introducing molten metal, of an aluminum base, the pouring temperature is in the range of 750-760°F (398-404°C) with the insert being heated to a temperature in the range of 262-342°F (128-172°C).

The invention will now be described further, by way of example, with reference to the accompanying drawings, in which :

Figure 1 is a flow diagram of the method steps of this invention;

Figure 2 is an exploded view of parts of an internal combustion engine showing locations for applying this invention within such engine;

Figure 3 is an enlarged perspective exploded view of the bottom of an aluminum cylinder block showing main bearing supports and bearing caps with cast-in-place inserts of this invention;

Figure 4 is an enlarged sectional view taken centrally through one of the main bearings of Figure 3 showing the use of totally immersed or embedded inserts to control thermal expansion for a moving interface application;

Figure 5 shows schematically a mode for carrying out hot extrusion;

Figure 6 is a perspective view of fixture parts used to shape an insert for a bearing cap application;

Figure 7 is a perspective view showing a mould fixture and inserts for making both a moving interface and a rigid interface application;

Figure 8 is a schematic view, partially in section, of a block and aluminum head for an engine assembly showing rigid interface applications of the invention;

Figures 9 and 10 are photographs at different magnifications of metallographic cross-sections for the structure of Figure 3 showing the bonding of the insert to the cast part; and

Figure 11 is a graphical illustration of strain at various temperatures for different engine bearing materials.

Interfacing metals of differing thermal expansion characteristics or coefficient (TEC), such as aluminum and iron, in an internal combustion engine may lead to poor performance. In rigid interfaces, such as when using metal fasteners to bolt together components with TEC significantly different than the fasteners, it is difficult to maintain a consistent clamping force between the components at varying temperature conditions. In moving interfaces, such as iron crankshafts in aluminum bearing supports, performance problems may result from the large difference of coefficient of thermal expansion. Cast iron has a TEC of about  $6 \times 10^{-6}/^{\circ}\text{F}$  or  $12 \times 10^{-6}/^{\circ}\text{C}$ , and aluminum components have a TEC of about  $13 \times 10^{-6}/^{\circ}\text{F}$  or  $21 \times 10^{-6}/^{\circ}\text{C}$ . A main bearing running clearance of .0008 inches diametrically is ideal for good engine performance at normal operating temperatures, but when the aluminum casting is cooled, it will contract too much around the iron crankshaft, decreasing the running clearance to a point where required cold weather starting -40°C (-40°F) becomes difficult. Likewise, in above normal or hot running engines, the running clearance can increase to the point where excessive noise and oil consumption will result.

To overcome these problems, this invention provides a method of deploying ceramic fiber oriented metal matrix composites as inserts in a cast component having the higher coefficient of thermal expansion and which will serve as one of the interfacing metal parts. The cast-in-place inserts will locally reduce the TEC, for the metal of normally higher TEC, at the interface, closer to that of the metal part having the lower TEC, thereby controlling the dimensional fit or running clearance variation to provide good, consistent engine performance.

The method of this invention can provide for dimensionally stabilizing, against the effects of temperature variations, the interfaces between metal parts of differing thermal expansion characteristics. This is carried out, as shown in Figure 1, by primarily first casting molten metal (for a first part having the higher TEC) about an insert consisting of (i) a matrix of a metal comprised substantially of the metal having the higher TEC, and (ii) ceramic fibers, to form a first part. The fibers are aligned, during casting, to generally coincide with at least one direction of anticipated thermal growth that may interfere with the interface. Secondly, the parts are operatively assembled together to form the interface with the fibers oriented as predetermined. Steps preparatory to

5 casting for making and locating the inserts include first the step of extruding the metal powder similar to the metal having the higher TEC and ceramic fibers to form a billet. Next, the billet is severed to provide an insert and shaping the insert, if necessary, to orient the fibers in a predetermined manner different than what is inherent in the billet. Lastly, locating the insert in a mould to carry out the predetermined fiber orientation, while preheating the insert to 35-45% of the temperature of the molten metal for the first part.

### Dissimilar Metal Interfaces

10 In modern internal combustion engines there is now employed, at various locations throughout the engine, a mating of metals having dissimilar TEC, such as aluminum and cast-iron or steel. Other light metals such as titanium, magnesium, copper, and zinc may be employed which will have a high TEC. Other metals with low TEC may be employed, such as lead. Figure 2 shows some examples of moving interfaces employing dissimilar metals, which include: (i) the support of a cast-iron crankshaft 10 by aluminum bearing supports 11 cast integral in an aluminum crankcase 12 and/or employing aluminum main bearing caps 13, preferably cast integral with 15 an aluminum oil pan 24, (ii) rotary support of cast-iron camshaft 14 in integrally cast aluminum supports 15, (iii) a reciprocal or sliding interface between an aluminum piston 16 and iron liner 17 of a cylinder block 18, and (iv) the aluminum piston 16 riding directly against the cylinder bores of an iron block utilizing a ringless piston concept. Examples of rigid interfaces include: (i) a cast-iron exhaust manifold 19 fastened by steel bolts 20 to aluminum cylinder head 21, (ii) iron main bearing caps 9 fastened to an aluminum casting for cylinder block 18 by use of steel or iron-based threaded fasteners 22, and (iii) a cast aluminum intake manifold 9 fastened to an iron or aluminum cylinder block 18 by steel bolts 23. In the rigid interface examples, the iron-based fasteners will respond to temperature environments differently than the threaded support comprised of aluminum. This may lead to unusual stress patterns and eventual loosening of the fasteners within the threaded support.

### Moving Interface Application

25 In a moving interface, such as a curved cylindrical surface about a rotatable shaft, the circumference of the interfacing surface of the parts with the higher TEC has to increase or grow at higher temperatures. Therefore, the direction to restrain is a curvilinear one, aligned with the circumference. Thermal growth in other directions perpendicular to such circumference has little effect on an interface of mating cylindrical surfaces. This is true also for a sliding interface, such as a cylindrical piston reciprocating against a cylindrical bore wall in a 30 ringless piston application. In a three-dimensional interface, such as in a universal ball and socket interfit, it may be necessary to restrain thermal growth in two mutually perpendicular but circumferential directions; thus, the fibers must accordingly be aligned in both such directions.

35 As shown in Figures 3-4, an assembly 25 is provided for supporting a first part 26 (comprised of a nodular iron crankshaft) within a second part or assembly 27-28 comprised of aluminum alloy die-cast bearing supports. One of the latter is a main bearing support 27 integrally cast with the aluminum alloy cylinder block, and the other is a main bearing cap 28 cast independently and secured to the main bearing support 27 by suitable threaded fasteners 29. An interface is created between the moving or rotatable first part 26 and the fixed second 40 part 27-28, bringing them together with two half-shell bushing type bearings 30 interposed therebetween. The second part 27-28 will experience thermal growth in a three-dimensional mode, but the most critical direction is that which is along the circumference and annular interface.

45 To achieve dimensional stability of the interface, a metal matrix composite insert 32 is formed by compacting, hot extrusion, shaping, and then casting it in-place within each of the second parts 27-28. The insert modifies the rate of thermal expansion coefficient for the second part adjacent at the interface to provide dimensional stability in a temperature environment of minus -40 to 260°C (40°F to 500°F). Such metal matrix composite insert is comprised of a matrix 33 consisting of rapidly solidified aluminum alloy powder and ceramic fibers 34 oriented in a predetermined manner. Preferably, the matrix metal is an aluminum alloy consisting of 8-15% (by weight) Si, .5-4.5% Cu, 20 .05-.7% Mg and the remainder Al. The powder is prealloyed and formed 50 by inert gas atomization for rapid solidification.

55 Candidate fibers include sialon, silicon nitride, silicon carbide, aluminosilicates, and alumina. As shown in Table I, their coefficients of thermal expansion are  $3.0 \times 10^{-6}/^{\circ}\text{C}$ ,  $3.3 \times 10^{-6}/^{\circ}\text{C}$ ,  $4.3 \times 10^{-6}/^{\circ}\text{C}$ ,  $5.1 \times 10^{-6}/^{\circ}\text{C}$ , and  $8.1 \times 10^{-6}/^{\circ}\text{C}$ , respectively, each of which is smaller than that of the thermal coefficient of expansion for cast-iron. Also, each has a strength and modulus of elasticity which is high for supporting the stresses induced when restricting the thermal expansion of the aluminum alloy matrix during heating; this is important for engine bearing applications. By manipulating the content of the fiber versus the matrix, the resulting insert can be selectively tailored to have a coefficient of thermal expansion approach or equal that of cast-iron unidirectionally by controlling the volume percent fiber from 5% to 55%. Selection of ceramic fiber type, matrix alloy,

and volume percent, the TEC can be adjusted to match the TEC of many other light metals having high TEC. For example, a blend of 20 volume percent SiC with 6061 rapidly solidified aluminum alloy yielded an insert TEC of  $63/415 \times 10^{-6}/^{\circ}\text{C}$  ( $7/83 10^{-6}/^{\circ}\text{F}$ ), also shown in Table I.

The metal matrix powder for the insert 33 is blended with the ceramic fibers and may be warm or cold 5 pressed to form a green compact structure in preparation for hot extrusion. Full density is necessary to ensure the integrity of the article and attain the necessary mechanical properties for extrusion. Vacuum compaction or isostatic pressing at elevated temperatures and pressures to cure the green structure should not be used to achieve full density in the composite. High temperatures can cause an adverse reaction between the fibers and matrix metal, especially for silicon carbide fibers and reactive metals like aluminum and titanium. Such reaction 10 affects the integrity of the composites and their mechanical properties. Secondary phases, such as carbides, borides, silicides or nitrides, can be formed in these reactive composites and are predictably based upon thermal dynamic considerations. Avoidance of an adverse reaction can be accomplished by plastically deforming the matrix metal to impart a significant strain energy to the metal, mixing the strain energized metal with the ceramic fibers (preferably having an aspect ratio (1/d) of 20-200). Strain energy can be imparted in a number 15 of ways: one way is to pass spherical, prealloyed metal particles through opposed rolls. The strain energy stored in the metal allows subsequent extrusion to occur at lower temperatures so that adverse reactions do not occur between the fibers and the matrix metal. However, plastic deformation is not necessary for making green compacts of aluminum alloy metal and silicon nitride fibers since the alloys have relatively low melting points and are softer than other light metals such as titanium alloys. Even without imparting strain energy to the matrix 20 metals, the processing temperatures can remain low enough that the alloy and silicon nitride fibers will not react and the fibers will not degrade.

Forming composites with continuous or very long fibers often requires highly specialized fabrication techniques to blend the fibers and to avoid (1) fiber breakage, (2) fiber bunching, (3) nonuniform fiber/matrix interfacial bonding, and (4) void concentrations. Semi-long whiskers or particulates are more readily used for, 25 hot extrusion of this invention. Agglomeration of the fibers should be avoided during blending; vibrating the mixture has proven as one means to achieve the desired dispersion. Machining, drilling, grinding, joining, and other operations are also more readily accomplished with composites having discrete or discontinuous fibers, since the properties of the composite are not as severely linked to the continuity of the fiber.

As shown in Figure 5, the green body 40 is hot extruded by being passed through a die opening 42 of die 30 41 using a power feed 43. The reduction ratio of the hot extrusion process should be greater than 10:1. Extrusion is carried out at a temperature between  $500-600^{\circ}\text{C}$  at a pressure of  $1.4 \times 10^5 - 2.8 \times 10^5 \text{ kPa}$  (20-40 ksi) for Al metal matrix composites; extrusion of titanium may be at a temperature of about  $500-700^{\circ}\text{C}$  and at a pressure of about  $3.45 \times 10^5$  (50 ksi). Such temperatures are achieved by use of an induction heater 44. The output of the die will be a continuous billet 45 having higher percent fiber orientation and greater unidirectional strength 35 along its axis 46 than conventional powder metallurgy composites. Preferably, the extruded Al/SiC composite will have a tensile strength at room temperature of about  $50 \text{ Kg/mm}^2$ , a tensile strength at  $200^{\circ}\text{C}$  of about  $28 \text{ Kg/mm}^2$ , and a compressive strength of about  $6.5 \text{ Kg/mm}^2$ .

The billet is severed into discrete inserts 47 and then shaped to orient the fibers in a predetermined arcuate manner to maximize the resistance to the direction of circumferential thermal growth. To this end, the elongated 40 insert 47 is placed in a crescent-shaped cavity 49 of a fixture 48, such as shown in Figure 6. The material is preferably heated to a temperature of about  $404^{\circ}\text{C}$  ( $760^{\circ}\text{F}$ ) for a period of about 20 minutes and bent to the shape of the die cavity by use of the fixture 48 and an arc-shaped punch 50 (both heated to about  $232^{\circ}\text{C}$  ( $450^{\circ}\text{F}$ ) having provision 51 for receiving part of the insert. The fibers will be aligned in a direction generally along the circumference of the interface for the part into which it is to be cast.

To cast the arc-shaped inserts 47 in place within the aluminum crankcase supports or caps requires, first, 45 preheating the insert 47 to approximately 35-45% of the temperature of the molten metal used to make the casting. As shown in Figure 7, the heated inserts 47 are transferred to a die-casting mould prior to the addition of the molten aluminum alloy. The mould has die parts consisting of a cope 52 and drag 53; the metal matrix composite inserts are positioned within the mould by the use of pegs 54. The inserts are positioned so that their concave surface 55 will lie approximately .15 - .3cm (.06-.12 inches) from the curved interface 56 of the light metal cast part. As the molten aluminum is poured into the mould, it surrounds the inserts; the molten metal is preferably poured at a temperature of  $399 - 404^{\circ}\text{C}$  ( $750-760^{\circ}\text{F}$ ). Any protective alumina coating is broken up as a result of the stresses induced by the thermal shock created at the insert/molten metal confrontation. Breaking up the protective alumina coating on the insert surface improves the wetting at the interface and promotes an excellent bond to the casting when cooled.

Rigid Interface Application

As shown in Figures 7 and 8, a rigid interface application is illustrated wherein steel bolts 59 are received through in a metal part 60 (of the higher TEC) having cast-in-place, sometimes internally threaded, cylindrical fiber reinforced inserts 61. Thermal expansion of the light metal bearing cap 60 may far exceed the thermal expansion of the steel bolts leading to a loosening of clamping pressure on the caps and distortion of the bearing surface 64 for the crankshaft 62. The cylindrical metal matrix composite inserts provide a solution to essentially a unidimensional thermal growth problem in this application; the inserts are exposed to the interface 91 with the heavy metal part.

In a rigid interface, dimensional stability must be obtained in a direction along the axis of fastener or bolt tension. Thermal growth in directions other than along such axis will not interfere with loosening of the bolt.

To carry out the method for this application, the same mixture, ceramic fibers and metal alloy powder, compaction pressures, and hot extrusion pressures are used for the making of the inserts. However, the extrusion is of a hollow cylinder with the fibers 65 oriented in a direction parallel to axis 63 of the cylinder. In this manner, the fibers will be generally parallel to the direction of anticipated thermal growth at the threaded interface which may interfere with bolt tension.

The cylindrical inserts 61 are each shaped by techniques to receive the steel bolts. The inserts are then placed in a mould, as shown in Figure 7, on pins 66 for stationing the inserts with the fibers in a predetermined orientation in shoulders 68 of the light metal part. Preheating temperatures for the inserts and molten light metal temperatures are used as in the previous embodiment described. Upon solidification of the cast light metal part, it is brought together with the heavy metal part (steel bolt) by threadably securing the bolts through the bearing cap and support and through the threaded cylindrical inserts.

**Examples**

Iron, aluminum and composite aluminum metal matrix composite inserts were made into test castings and bolted together for testing. The metal matrix composite for these castings was comprised of 20 volume percent SiC in a 6061 rapidly solidified Al powder. The bore diameters of all three assemblies were measured as a function of temperature over the range from -40° to 204°C (-40 to 400°F). A telescoping gauge was used to measure the bore diameter at three orientations. From these measurements, the mean bore diameter for each temperature was calculated. This information was then used to determine (for each material): the diametrical strain, the TEC, and an estimate of the main bearing/crankshaft running clearances at temperature ranging from -40°C to 149°C (-40°F to 300°F) (see Table II).

A summary of the diametrical strain variations of the test assembly bores as a result of temperature changes is shown in Figure 11. The lines through the data points were determined with linear regression analysis and the slope of each line represents the TEC at the bored holes for each of the assemblies. The TEC for both the all-iron and all-aluminum assemblies determined in these examples agree well with published values. As shown, the cast-in-place MMC inserts with SiC were effective in reducing the thermal expansion coefficient of cast aluminum to a value about midway between that of cast aluminum and cast iron.

In Table II, and as shown for an iron crankshaft with iron bearing caps, the clearance range will not change with temperature because the thermal expansion is the same. However, calculations show that when cast aluminum bearing caps or girdles are used, seizure of the crankshaft may occur at -40°C (-40°F). At the higher engine operating temperatures, the clearances are considered excessive (both minimum and maximum values) and will probably result in a noisy engine and excessive oil consumption at the main bearings. By adding the cast-in-place MMC inserts (20% SiC) to the casting aluminum bearing caps, calculations indicate that the main bearing clearance variations will be reduced substantially. With clearance tolerances in the specified range at room temperature, it should be possible to crank, the engine at -40°C (-40°F). However, at higher engine temperatures the clearances will be higher than that for cast iron engines with iron bearing caps, but approximately the same as for aluminum engines with iron bearing caps.

To obtain a lower TEC than that of the 20% SiC material, a fiber with a lower TEC than SiC is selected and combined with a higher fiber loading in the matrix. A review of possible reinforcing fibers (Table I) shows that silicon nitride and sialon are useful. Assuming that the maximum theoretical loading of -50% can be achieved, calculations based on the law of mixtures show that the TEC at the bored hole will be approximately  $12.1 \times 10^{-6}/^{\circ}\text{C}$  ( $6.7 \times 10^{-6}/^{\circ}\text{F}$ ), which approaches that of iron  $11.2 \times 10^{-6}/^{\circ}\text{C}$  ( $6.2 \times 10^{-6}/^{\circ}\text{F}$ ). The crankshaft/main bearing clearances will be equivalent to that of cast iron.

It is important to have a good metallurgical bond between the MMC insert and the aluminum casting for maximum long-term durability, especially when the engine is routinely operated over a wide temperature range. As shown by metallographic cross-sections (Figures 9 and 10), the bonding of this insert material to the cast

aluminum parts was excellent. The MMC/aluminum casting interface showed no evidence of voids or lack of bonding on any of the parts.

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TABLE I

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## THERMAL EXPANSION COEFFICIENT OF SELECTED MATERIALS AND FIBERS

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<u>MATERIAL</u>	<u>THERMAL EXPANSION COEFFICIENT</u>	
	<u><math>\times 10^{-6}/^{\circ}\text{F}</math></u>	<u><math>\times 10^{-6}/^{\circ}\text{C}</math></u>
Sialon Fiber	1.66	3.0
Silicon Nitride Fiber	1.83	3.3
Silicon Carbide Fiber	2.39	4.3
Aluminosilicate Fiber	2.83	5.1
Alumina Fiber	4.50	8.1
Aluminum	14.0	
20% vol. % SiC fibers in rapidly solidified Al matrix	7.83	
50 vol. % $\text{Si}_3\text{N}_4$ fibers in rapidly solidified Al matrix	6.7	
Nodular Cast Iron	6.0	

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TABLE II

MAIN BEARING/CRANKSHAFT JOURNAL RUNNING CLEARANCES FOR  
DIFFERENT BEARING MATERIALS AROUND A CAST IRON CRANKSHAFT

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MAIN BEARING MATERIAL	RUNNING CLEARANCES ( $\times 10^{-3}$ in.) ( $\times 2.5 \times 10^{-3}$ cm)		
	-40°C (-40°F)	TEMPERATURE ROOM	149°C (300°F)
IRON	1.8 2.6	1.8 min 2.6 max	1.8 2.6
ALUMINUM	-0.2 0.6	1.8 min 2.6 max	5.5 6.3
AL/MMC*	0.6 1.4	1.8 min 2.6 max	3.9 4.7
AL/MMC**	1.6 min 2.4 max	1.8 min 2.6 max	2.3 3.1
Upper half AL - IRON CAP	0.8 1.6	1.8 2.6	3.6 4.5
Upper half AL/MMC - IRON CAP	1.2 2.0	1.8 2.6	2.9 3.7
Upper Half AL/MMC** - IRON CAP	1.6 2.4	1.8 2.6	2.1 2.9

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\*Composite with 20 vol. % SiC in RS/AL matrix; TEC value of  $7.83 \times 10^{-6}/^{\circ}\text{F}$ .

\*\*Composite with 50 vol. %  $\text{Si}_3\text{N}_4$  or sialon fibers in Al matrix; TEC value ( $6.7 \times 10^{-6}/^{\circ}\text{F}$ ) ( $12.1 \times 10^{-6}/^{\circ}\text{C}$ )

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## Claims

1. Method of dimensionally stabilizing the interface between metal parts of differing thermal expansion characteristics (TEC), a first part having the higher TEC and a second part having the lower TEC, regardless of temperature variations under normal designed use of such parts, comprising: before bringing together said first part with the second metal part for forming said interface:

– locating an insert in a mould to cast it in place in the first part of the interface,

introducing molten metal into the mould for such first part,  
 characterised in, before locating said insert in the mould

(a) hot extruding a mixture of ceramic fibers having TEC less than either of said parts and rapidly solidified metal powder comprised substantially of the metal having the higher TEC, while aligning the fibers generally along the direction of extrusion, to form a billet;

5 (b) severing said insert from the billet and shaping it to orient its fibers parallel to at least one direction of anticipated thermal growth of the first part, that would interfere with said interface;

(c) while locating said insert in the mould for positioning it to carry out said orientation of step (b), said insert being preheated to a temperature in the range of 35-45% of the temperature of the molten metal for

10 the first part to be poured into the mould.

2. A method as claimed in claim 1, in which said metal for said first part and powder is a metal or alloy thereof selected from the group consisting of aluminum, magnesium, titanium and copper.

3. A method as claimed in claim 1, in which said ceramic fibers are selected from the group consisting of silicon nitride, sialon, silicon carbide, aluminum silicate and alumina.

15 4. A method as claimed in claim 1, in which said metal for said first part is aluminum or aluminum alloy and step (a) is carried out using greater than 10:1 reduction and an extrusion temperature greater than 400°C.

5. A method as claimed in claim 1, in which in step (b) said insert is shaped by heating to a temperature of about 300°C for about 20 minutes while punching the insert to the desired shape.

20 6. A method as claimed in claim 1, in which in step (c) said insert is located to be embedded within the first part at a distance of .15 - .3 cms (.06-.12 inches) from the surface of the first part.

7. A method as claimed in claim 1, in which said insert is positioned in the mould in step (c) to have a surface coincident with the surface of the first part and thereby be exposed.

8. A method as claimed in claim 1, in which said mixture is essentially devoid of organic material.

9. A method as claimed in claim 1, in which said first part is aluminium-based automotive part and said

25 second part is iron based automotive part.

10. An assembly of interfacing dissimilar metals in an internal combustion engine, said metals having differing thermal expansion characteristics (TEC), comprising:

(a) a first part comprised of a metal having the higher TEC, said first part presenting a first interface surface;

30 (b) a second part comprised of a metal having the lower TEC and presenting a second interface surface to mate with said first interface surface, said first part having a cast-in-place metal insert characterised in that the cast-in-place metal insert is a metal matrix composite insert in which the metal of the matrix is substantially the same as the metal of said first part and contains a ceramic phase consisting of ceramic fibers aligned generally in at least one direction of anticipated thermal growth of the second part that may interfere

35 with said interface.

11. An assembly as claimed in claim 10, in which said ceramic fibers are selected from the group consisting of SiC, Si<sub>3</sub>N<sub>4</sub>, Al<sub>2</sub>O<sub>3</sub>, and sialon.

12. An assembly as claimed in claim 10, in which said insert consists of an extruded mixture of rapidly solidified metal power and aligned ceramic fibers.

40 13. An assembly as claimed in claim 10, in which said second part is an iron crankshaft and said first part is an aluminum bearing support.

14. An assembly as claimed in claim 10, in which said second part is a steel bolt and said first part is an aluminum member to be secured by said bolt to a third part.

15 An assembly as claimed in claim 10, in which said parts provide for a moving interface between cylindrical surfaces, and said ceramic fibers are aligned to resist circumferential thermal growth about the interface of the first part.

45 16. An assembly as claimed in claim 10, in which said parts have a rigid interface to provide a clamping force along one direction, and said ceramic fibers are aligned to resist thermal growth along said direction.

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### Patentansprüche

1. Methode zur Formstabilisierung der Grenzfläche zwischen Metallteilen mit unterschiedlichen Wärmeausdehnungskoeffizienten (WAK), wobei ein erstes Teil den höheren WAK und ein zweites Teil den niedrigeren WAK aufweist, und zwar unabhängig von den Temperaturveränderungen, die bei derartigen Teilen unter normalen Betriebsbedingungen auftreten, umfassend, bevor das genannte erste Teil mit dem zweiten Metallteil zwecks Bildung der genannten Grenzfläche zusammengefügt wird:

55 – das Einlegen eines Einlegeteiles in eine Form, um so ein Eingießen im ersten Teil der Grenzfläche zu

erreichen,

das Einführen von geschmolzenem Metall in die Form zur Herstellung eines derartigen ersten Teiles,

gekennzeichnet, bevor das genannte Einlegeteil in die Form eingelegt wird, durch folgende Schritte:

5 a) Heißextrudieren einer Mischung aus Keramikfasern, deren WAK jeweils geringer als derjenige der genannten Teile ist, und aus schnell erstarrendem Metallpulver, das im wesentlichen aus dem den höheren WAK aufweisenden Metall besteht, wobei die Fasern im allgemeinen eine Ausrichtung in Extrusionsrichtung erfahren, um so einen Vorformling auszubilden;

10 b) Abtrennen des genannten Einlegeteiles vom Vorformling und Formen desselben, um so dessen Fasern parallel zu zumindest einer Richtung des zu erwartenden Wärmezuwachses des ersten Teiles, wodurch eine Beeinträchtigung der genannten Grenzfläche bewirkt werden würde, auszurichten;

15 c) gleichzeitiges Einlegen des genannten Einlegeteiles in die Form zwecks dessen Positionierung, um so die genannte Ausrichtung nach Schritt b) durchzuführen, wobei das genannte Einlegeteil eine Vorerwärmung auf eine Temperatur im Bereich von 35 bis 45% der Temperatur des geschmolzenen Metalls zur Herstellung des in die Form einzugießenden ersten Teiles erfährt.

2. Methode nach Anspruch 1, wobei es sich bei dem genannten Metall für das genannte erste Teil und bei dem Pulver um ein Metall oder eine Legierung davon handelt, das/die aus der Aluminium, Magnesium, Titan und Kupfer umfassenden Gruppe stammt.

3. Methode nach Anspruch 1, wobei die genannten Keramikfasern aus der Siliziumnitrid, Sialon, Siliziumkarbid, Aluminiumsilikat und Aluminiumoxid umfassenden Gruppe stammen.

4. Methode nach Anspruch 1, wobei es sich bei dem genannten Metall für das genannte erste Teil um Aluminium oder eine Aluminiumlegierung handelt, und wobei der Schritt a) bei einer Reduktion von mehr als 10:1 und einer Extrusionstemperatur von mehr als 400 °C stattfindet.

5. Methode nach Anspruch 1, wobei beim Schritt b) das Formen des genannten Einlegeteiles durch Erwärmen auf eine Temperatur von etwa 300 °C während eines Zeitraumes von etwa 20 Minuten erfolgt, während das Einlegeteil durch Stanzen die gewünschte Form erhält.

6. Methode nach Anspruch 1, wobei beim Schritt c) das genannte Einlegeteil eine derartige Anordnung erfährt, daß es innerhalb des ersten Teiles in einem Abstand von 0,15 bis 0,3 cm (0,06 bis 0,12") von der Oberfläche des ersten Teiles eingebettet ist.

7. Methode nach Anspruch 1, wobei das genannte Einlegeteil beim Schritt c) so in der Form angeordnet ist, daß es eine Oberfläche aufweist, die mit der Oberfläche des ersten Teiles zusammenfällt und dadurch zur Außenfläche wird.

8. Methode nach Anspruch 1, wobei die genannte Mischung im wesentlichen frei von organischen Bestandteilen ist.

9. Methode nach Anspruch 1, wobei es sich bei dem genannten ersten Teil um ein Autobauteil auf Aluminiumbasis und bei dem genannten zweiten Teil um ein Autobauteil auf Eisenbasis handelt.

10. Baueinheit aus einer Grenzfläche bildenden, unähnlichen Metallen in einem Verbrennungsmotor, wobei die genannten Metalle unterschiedliche Wärmeausdehnungskoeffizienten (WAK) aufweisen, umfassend:

40 a) ein erstes Teil aus einem Metall mit dem höheren WAK, wobei das genannte erste Teil eine erste Grenzfläche darstellt;

45 b) ein zweites Teil aus einem Metall mit dem niedrigeren WAK, das eine zweite Grenzfläche zwecks Anpassung an die genannte erste Grenzfläche darstellt, wobei das genannte erste Teil ein eingegossenes Metalleinlegeteil aufweist, dadurch gekennzeichnet, daß es sich bei dem eingegossenen Metalleinlegeteil um ein Metallmatrixverbundeneinlegeteil handelt, wobei es sich bei dem Metall der Matrix im wesentlichen um das gleiche Metall wie beim genannten ersten Teil handelt und dieses eine Keramikphase aus Keramikfasern umfaßt, die im allgemeinen in zumindest einer Richtung des zu erwartenden Wärmezuwachses des zweiten Teiles, wodurch eine Beeinträchtigung der genannten Grenzfläche bewirkt werden könnte, ausgerichtet sind.

50 11. Baueinheit nach Anspruch 10, wobei die genannten Keramikfasern aus der SiC, Si<sub>3</sub>N<sub>4</sub>, Al<sub>2</sub>O<sub>3</sub> und Sialon umfassenden Gruppe stammen.

12. Baueinheit nach Anspruch 10, wobei das genannte Einlegeteil aus einer extrudierten Mischung aus schnell erstarrendem Metallpulver und ausgerichteten Keramikfasern besteht.

13. Baueinheit nach Anspruch 10, wobei es sich bei dem genannten zweiten Teil um eine aus Eisen bestehende Kurbelwelle und bei dem genannten ersten Teil um eine aus Aluminium bestehende Lagerkonsole handelt.

55 14. Baueinheit nach Anspruch 10, wobei es sich bei dem genannten zweiten Teil um einen Stahlbolzen und bei dem genannten ersten Teil um ein mit Hilfe des genannten Bolzens an einem dritten Teil zu befestigenden Aluminiumelement handelt.

15. Baueinheit nach Anspruch 10, wobei die genannten Teile eine Bewegungsgrenzfläche zwischen zylindrischen Oberflächen schaffen, und wobei die genannten Keramikfasern so ausgerichtet sind, daß sie dem am Umfang auftretenden Wärmezuwachs an der Grenzfläche des ersten Teiles widerstehen.

5 16. Baueinheit nach Anspruch 10, wobei die genannten Teile eine starre Grenzfläche aufweisen, um so für eine Verbindungs Kraft in einer Richtung zu sorgen, und wobei die genannten Keramikfasern so ausgerichtet sind, daß sie dem Wärmezuwachs in der genannten Richtung widerstehen.

## Revendications

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1. Procédé pour stabiliser dimensionnellement la jonction entre des pièces métalliques de caractéristiques de dilatation thermique différentes (CDT), une première pièce présentant le coefficient de dilatation thermique le plus élevé et une seconde pièce présentant le coefficient de dilatation thermique le moins élevé sans tenir compte des variations de température dans une utilisation de conception normale de ces pièces, comprenant : avant d'amener en contact la première pièce avec la seconde pièce métallique pour former ladite jonction :

- placer une pièce rapportée dans un moule pour la couler en place dans la première pièce de la jonction,
- introduire le métal fondu dans le moule pour cette première pièce,
- caractérisé en ce que, avant de placer ladite pièce rapportée dans le moule

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(a) extruder à chaud un mélange de fibres de céramiques ayant un coefficient de dilatation thermique inférieur à chacun de celui des deux pièces et de poudre métallique solidifiée rapidement constituée principalement du métal présentant le coefficient de dilatation thermique le plus élevé, tout en alignant les fibres généralement le long de la direction d'extrusion pour former une billette ;

(b) découper ladite pièce rapportée à partir de la billette et la former pour orienter ses fibres parallèlement à au moins une direction de croissance thermique anticipée de la première pièce, qui devrait interférer avec ladite jonction ;

(c) tout en plaçant ladite pièce rapportée dans le moule, la positionner afin de réaliser ladite orientation de l'étape (b), ladite pièce rapportée étant préchauffée à une température se trouvant dans la plage de 35 à 45 % de la température du métal fondu pour la première pièce qui doit être coulée dans le moule.

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2. Procédé selon la revendication 1, dans lequel ledit métal pour ladite première pièce et la poudre est un métal ou alliage de celui-ci choisi dans le groupe qui est constitué de l'aluminium, du magnésium, du titane et du cuivre.

3. Procédé selon la revendication 1, dans lequel lesdites fibres de céramiques sont choisies à partir du groupe qui est constitué du nitrure de silicium, du sialon, du carbure de silicium, du silicate d'aluminium et de l'oxyde d'aluminium.

35 4. Procédé selon la revendication 1, dans lequel ledit métal pour ladite première pièce est de l'aluminium ou un alliage d'aluminium et l'étape (a) est réalisée en utilisant une réduction supérieure à 10:1 et une température d'extrusion supérieure à 400°C.

5. Procédé selon la revendication 1, dans lequel pendant l'étape (b) ladite pièce rapportée est formée en la chauffant à une température d'environ 300°C pendant 20 minutes tout en poinçonnant la pièce rapportée à la forme souhaitée.

40 6. Procédé selon la revendication 1, dans lequel pendant l'étape (c) ladite pièce rapportée est placée pour être encastrée à l'intérieur de la première pièce à une distance de 0,15 à 0,3 cm (0,06 à 0,12 pouces) de la surface de la première pièce.

7. Procédé selon la revendication 1, dans lequel ladite pièce rapportée est positionnée dans le moule pendant l'étape (c) pour avoir une surface coïncidant avec la surface de la première pièce et être de ce fait exposée.

45 8. Procédé selon la revendication 1, dans lequel ledit mélange est essentiellement dépourvu de matériau organique.

9. Procédé selon la revendication 1, dans lequel ladite première pièce est une pièce d'automobile à base d'aluminium et ladite seconde pièce est une pièce d'automobile à base de fer.

50 10. Construction à base de métaux dissemblables jointifs dans un moteur à combustion interne, lesdits métaux présentant des caractéristiques de dilatation thermique différentes (CDT), comprenant :

(a) une première pièce constituée d'un métal présentant le coefficient de dilatation thermique le plus élevé, ladite première pièce présentant une première surface de jonction ;

55 (b) une seconde pièce constituée d'un métal présentant le coefficient de dilatation thermique le moins élevé et présentant une seconde surface de jonction pour se lier à ladite première surface de jonction, ladite première pièce comportant une pièce rapportée métallique coulée en place, caractérisée en ce que la pièce métallique rapportée coulée en place est une pièce métallique de matériau composite métallique à phase dispersée dans laquelle le métal du matériau composite à phase dispersée est pratiquement le

même que le métal de ladite première pièce et contient une phase céramique constituée de fibres de céramiques alignées généralement dans au moins une direction de croissance thermique anticipée de la seconde pièce qui peut interférer avec ladite jonction.

11. Construction selon la revendication 10, dans laquelle lesdites fibres de céramiques sont choisies dans 5 le groupe constitué de SiC, Si<sub>3</sub>N<sub>4</sub>, Al<sub>2</sub>O<sub>3</sub> et sialon.
12. Construction selon la revendication 10, dans laquelle ladite pièce rapportée est constituée d'un mélange extrudé de poudre métallique rapidement solidifiée et de fibres de céramiques alignées.
13. Construction selon la revendication 10, dans laquelle ladite seconde pièce est un vilebrequin en fer et ladite première pièce est un support de palier en aluminium.
- 10 14. Construction selon la revendication 10, dans laquelle ladite seconde pièce est un boulon en acier et ladite première pièce est un élément en aluminium qui doit être fixé pour ledit boulon à une troisième pièce.
15. Construction selon la revendication 10, dans laquelle lesdites pièces sont prévues pour une jonction mobile entre des surfaces cylindriques, et lesdites fibres de céramiques sont alignées pour résister à la croissance thermique circonférentielle autour de la jonction de la première pièce.
- 15 16. Construction selon la revendication 10, dans laquelle lesdites pièces présentent une jonction fixe pour assurer une force de serrage le long d'une direction et lesdites fibres de céramiques sont alignées pour résister à la croissance thermique le long de ladite direction.

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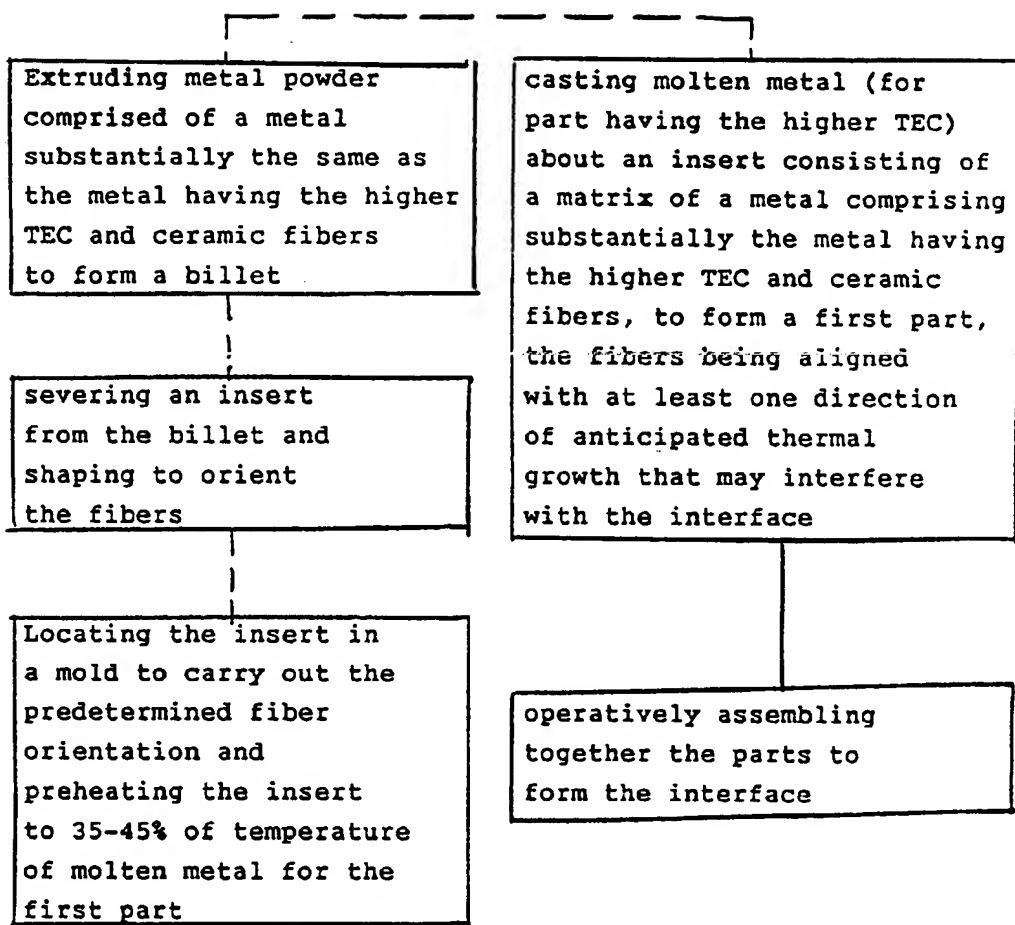


FIG.1

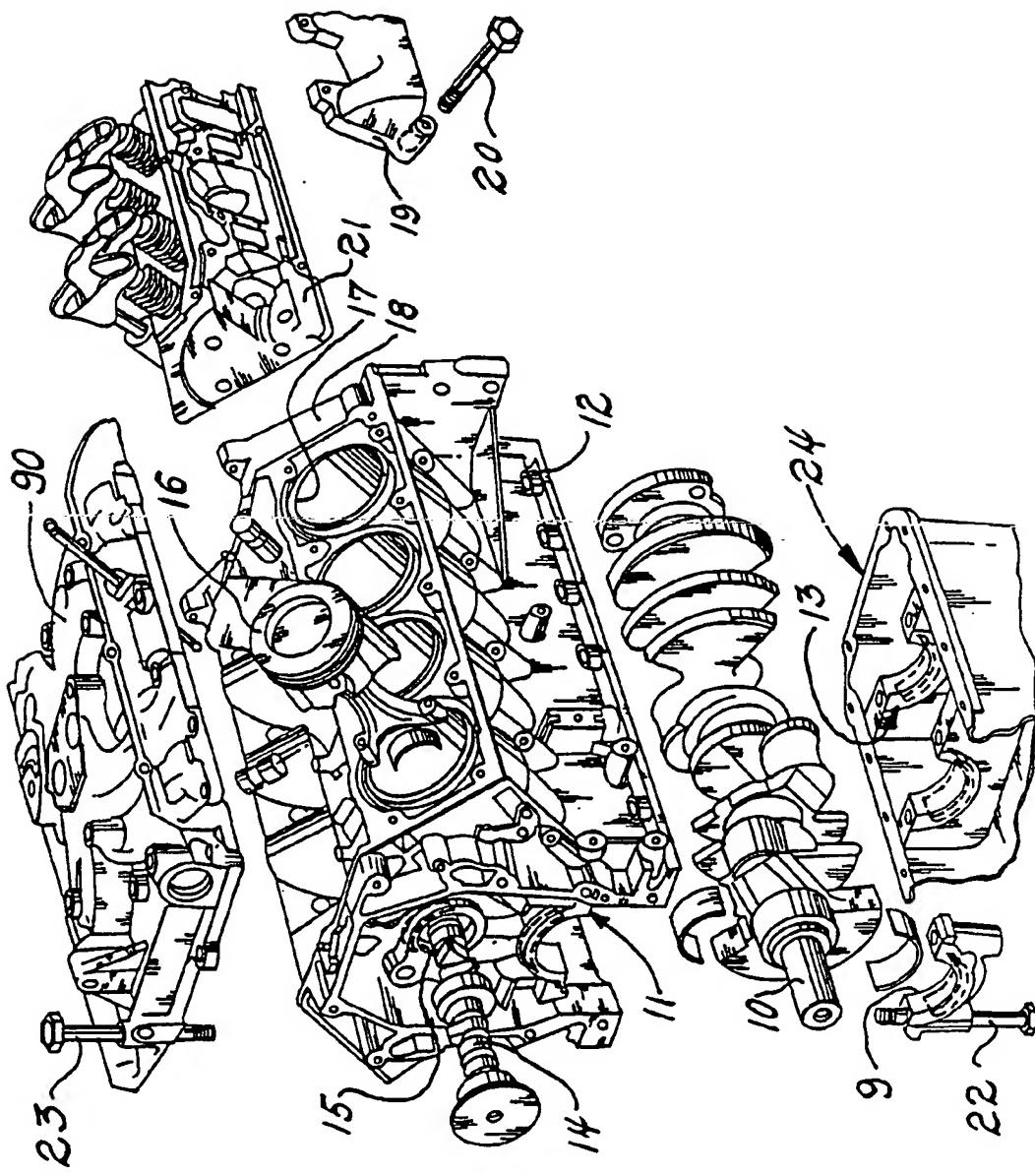
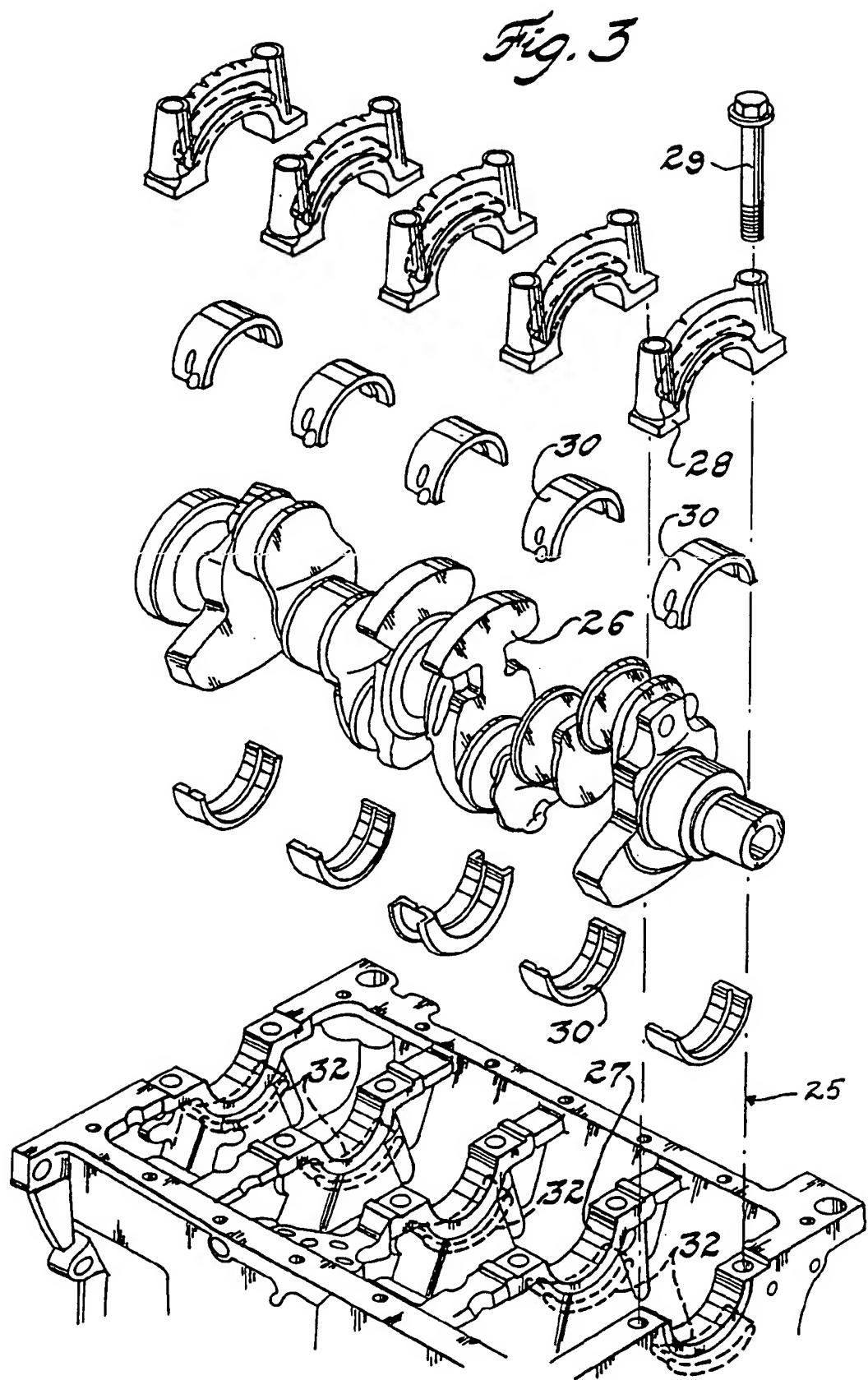
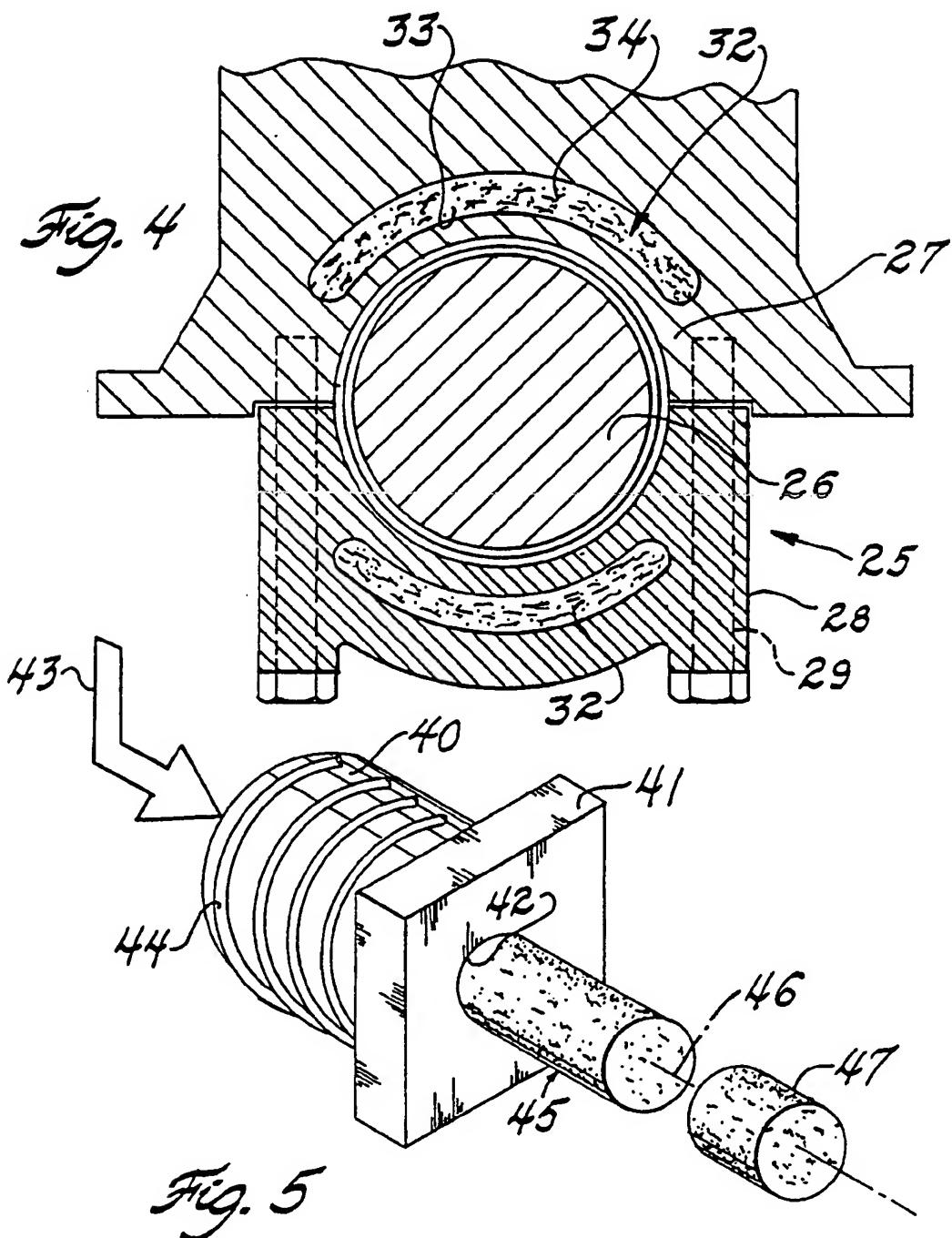


Fig. 2





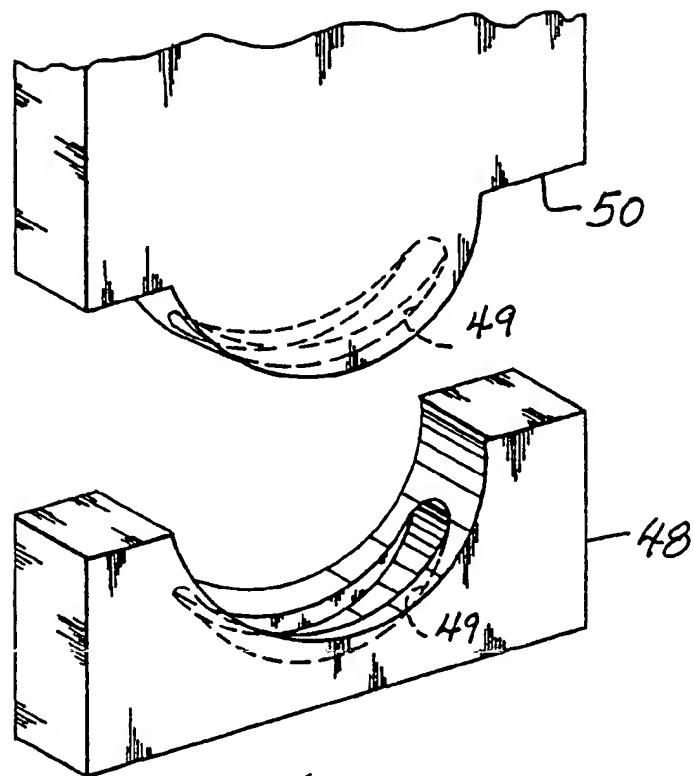


Fig. 6

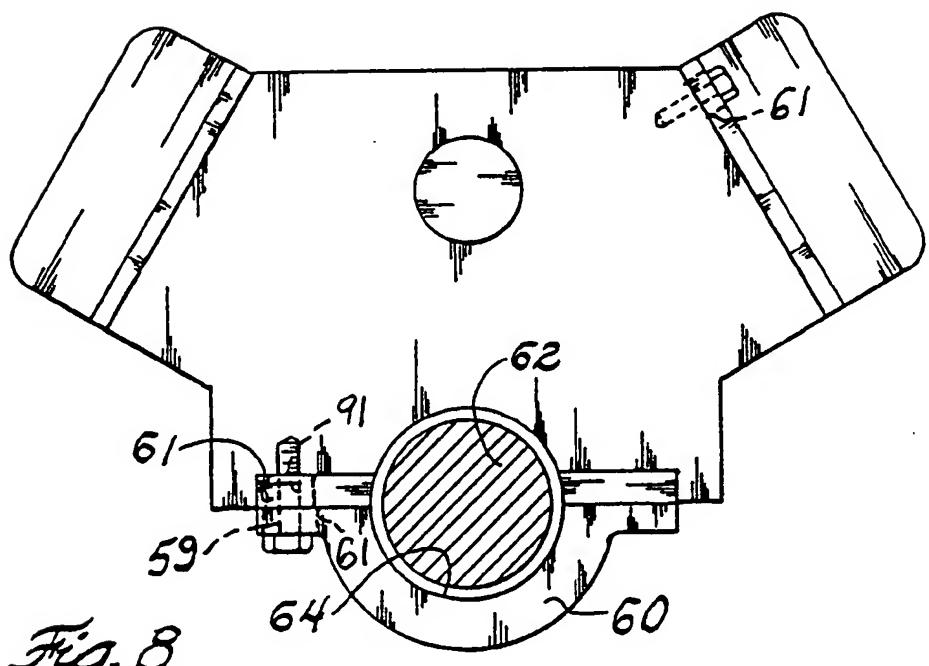


Fig. 8

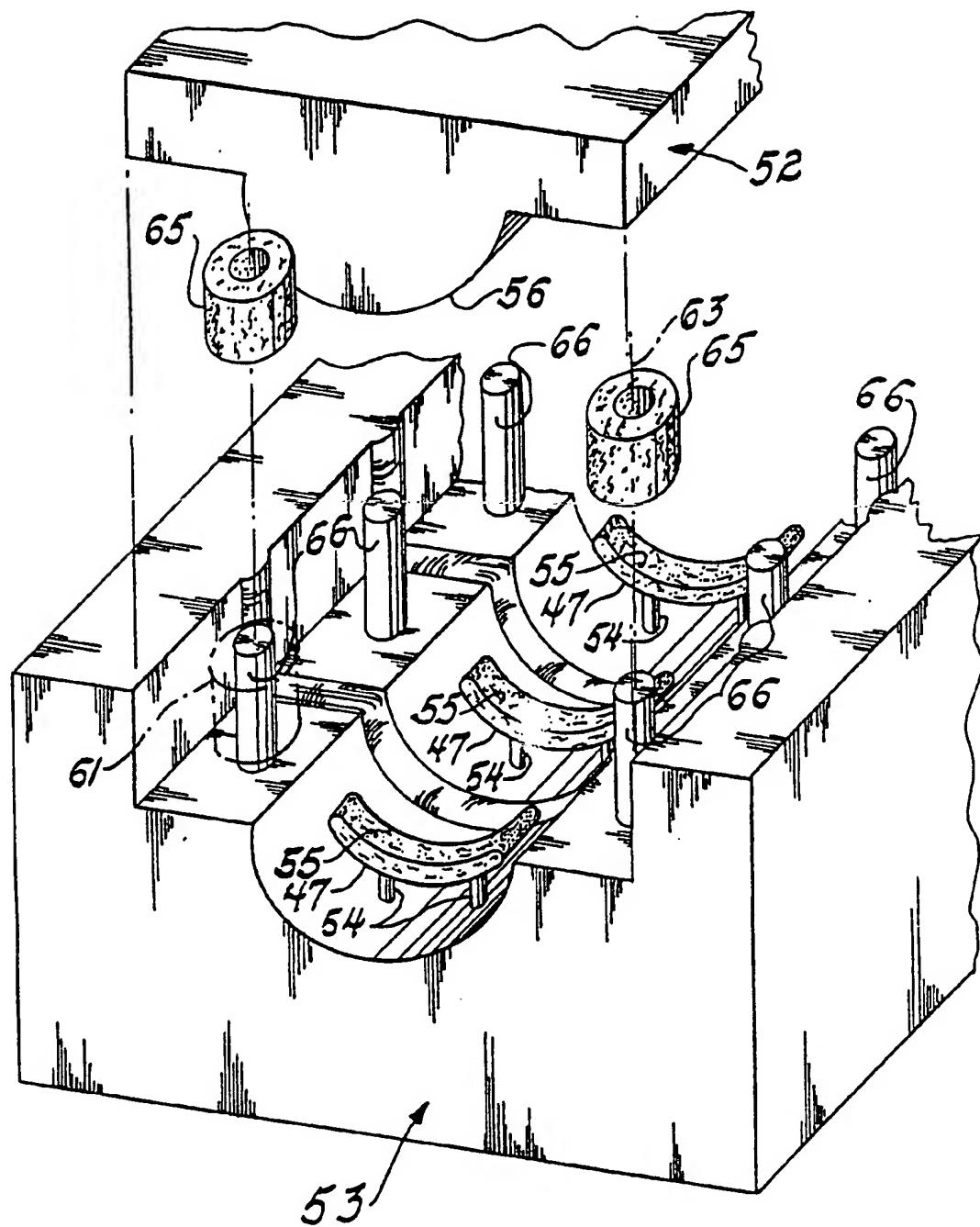


Fig. 7

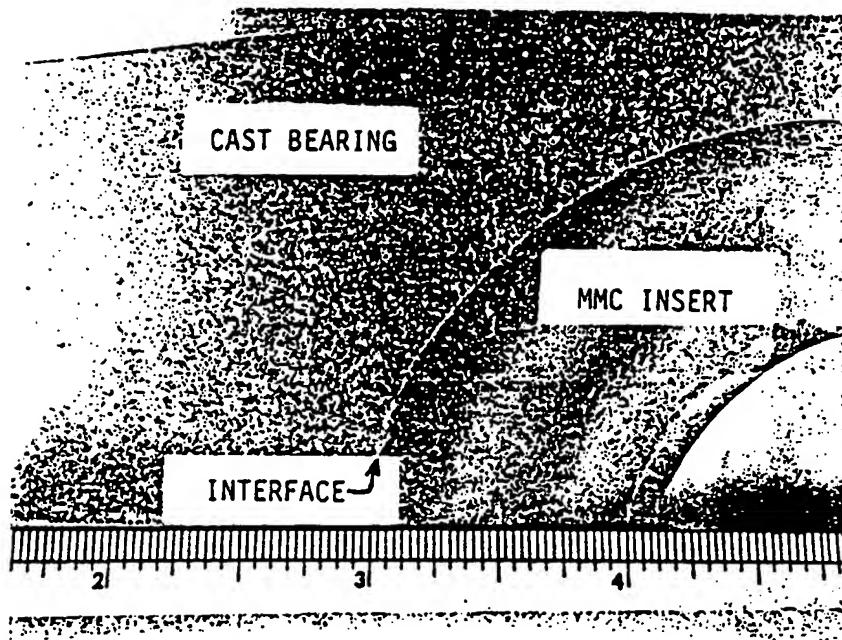


FIG. 9 1.4X Magnification

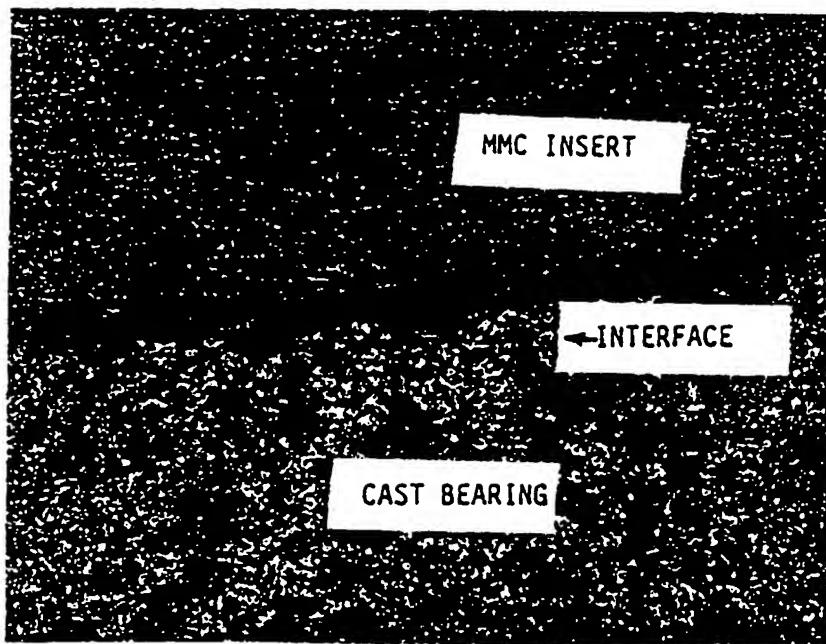
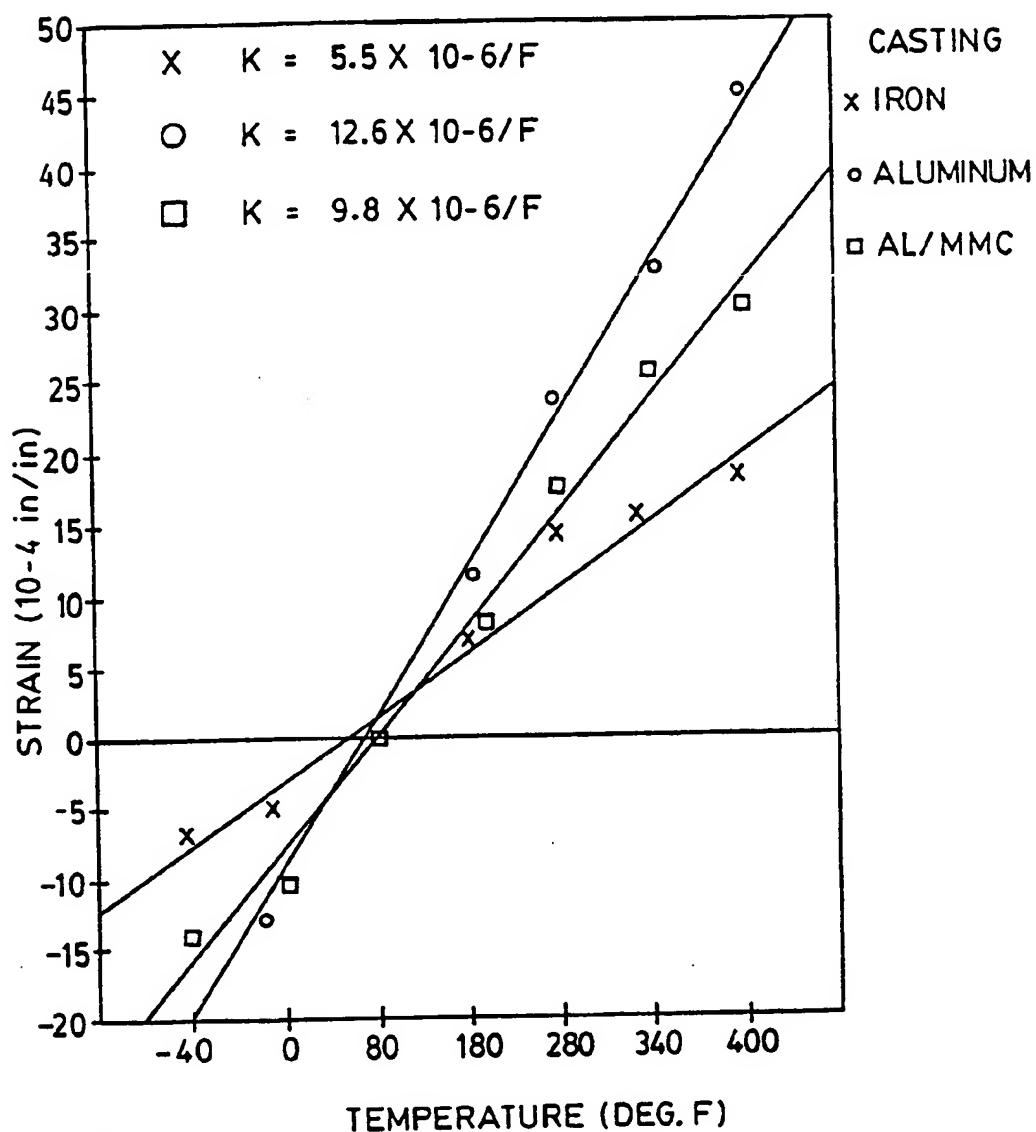


FIG. 10 20X Magnification

Photographs of metallographic cross sections showing the excellent metallurgical bonding of the MMC insert with the cast aluminum main bearing.

DIAMETRICAL STRAIN AT VARIOUS  
TEMPERATURES FOR DIFFERENT ENGINE  
MAIN BEARING MATERIALS



*Fig. 11*